Near infrared reflectance spectroscopy and molecular tools to evaluate land use impact on soil quality

A case study in a tropical ecosystem (altitude plains, Lao PDR)

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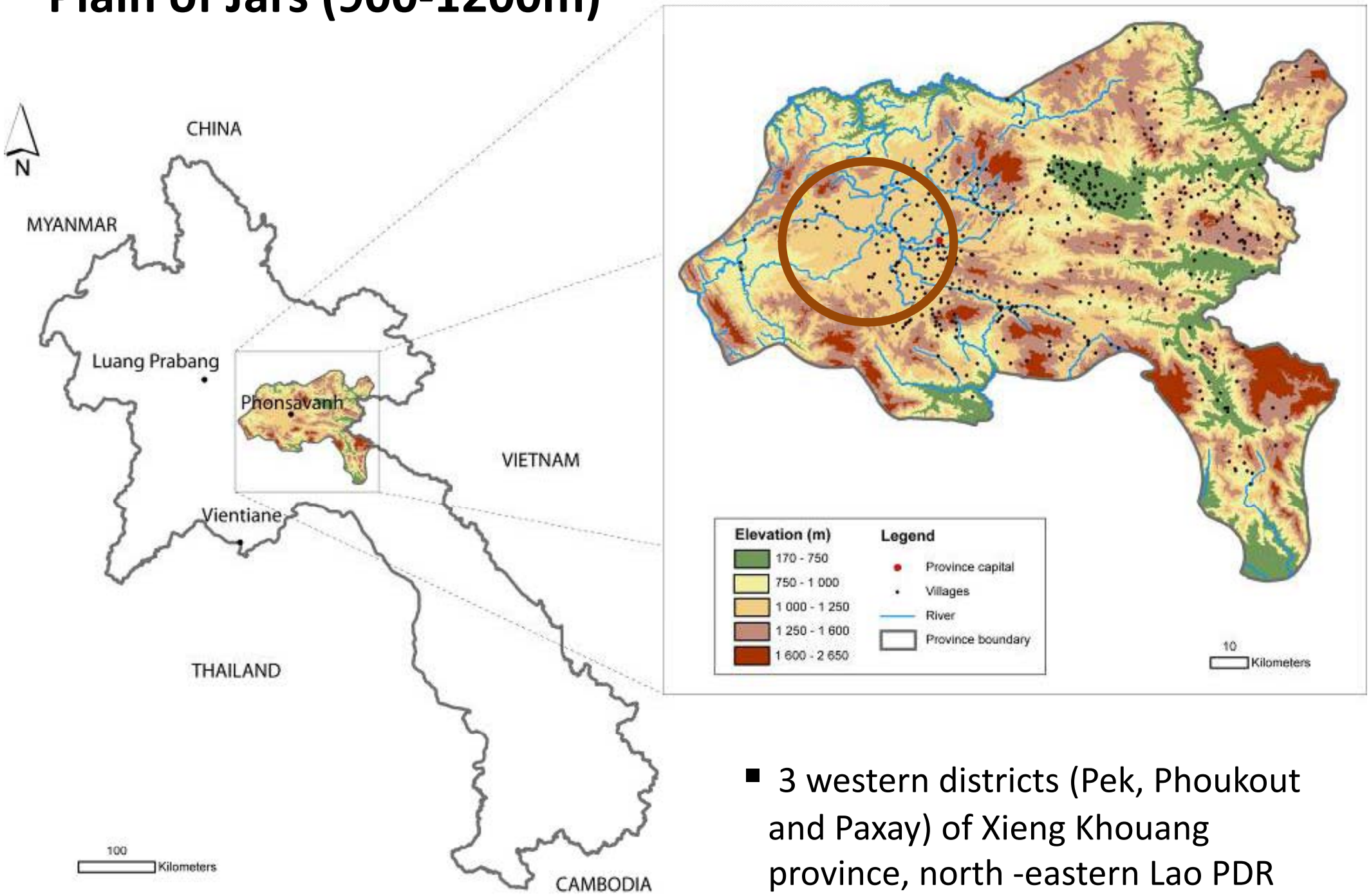
CONTENT

- Recent land use changes in the Plain of Jars, Lao PDR
- Monitoring of land use changes impact on soil properties
- Main outputs regarding Near Infrared Reflectance Spectroscopy (NIRS) predictive potential
- Conclusions

Plain of Jars (900-1200m)



- 3 western districts (Pek, Phoukout and Paxay) of Xieng Khouang province, north -eastern Lao PDR

Plain of Jars (900-1200m)

- About 80.000 ha of savannah grasslands with pine trees on hills summit
- Main farming system: rice production in paddy fields
- Limited possibilities to extend paddy areas
- Limited agricultural production in the upland due to soil constraints (low pH, deficiencies in main nutrients, severe aluminium toxicity)
- Only 5% of total surface is cultivated, 80% in paddy rice fields
- Extensive livestock system in the uplands

Main changes in the uplands

- Since 1990's

  Reforestation (pine trees) policy and upland rice production attempts based on plowing with disks

- Since 2000's

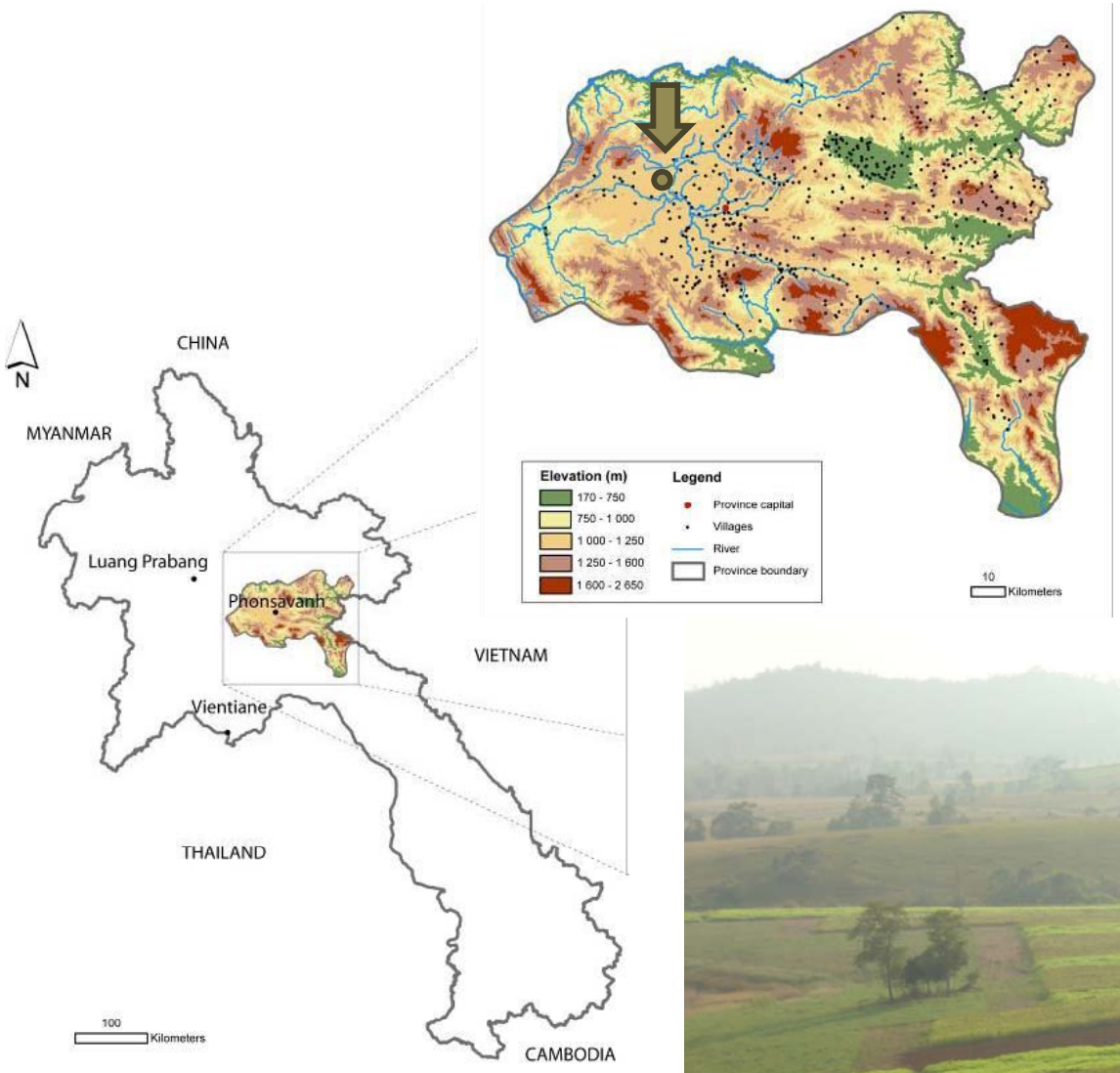
  Attribution of large concessions to private companies for cash crops production (cassava, corn, jatropha); land preparation based on deep soil plowing

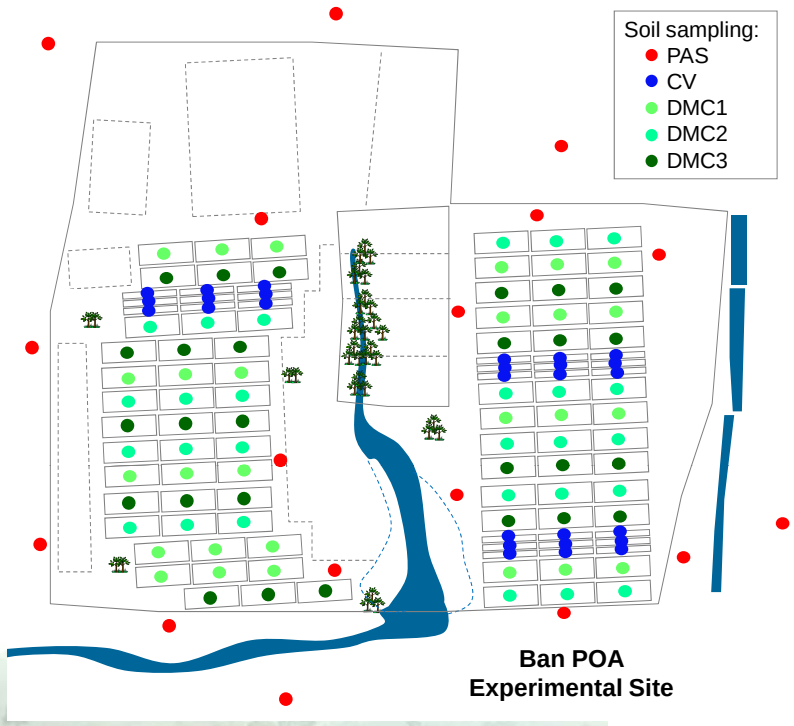
- Since 2005

  Conception and promotion of Conservation Agriculture (CA) / Direct-seeding Mulch-based Cropping (DMC) systems based on:
  - Permanent / maximum soil cover
  - Minimum soil disturbance (no-tillage)
  - Diversified crops rotations

Little information regarding agricultural practices impact on soil quality…

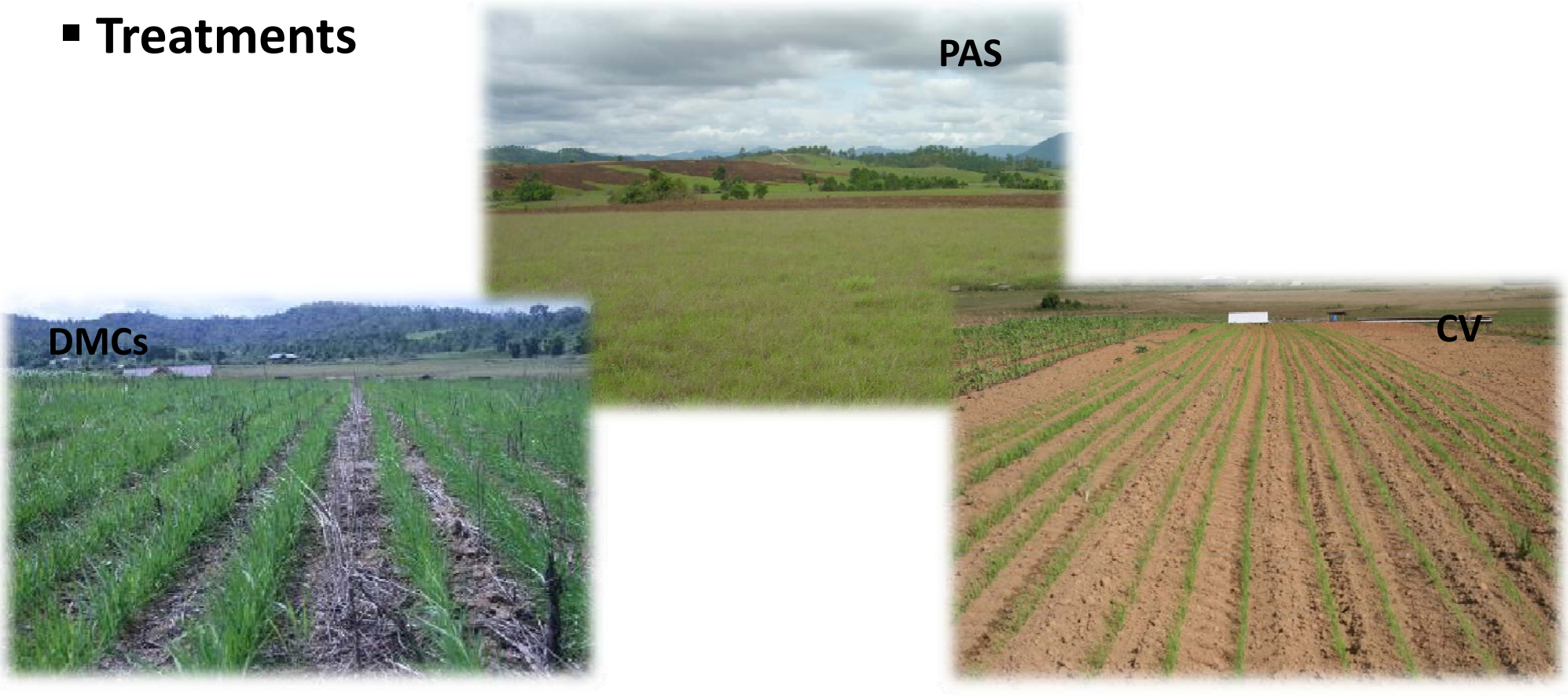
Ban Poa experimental site



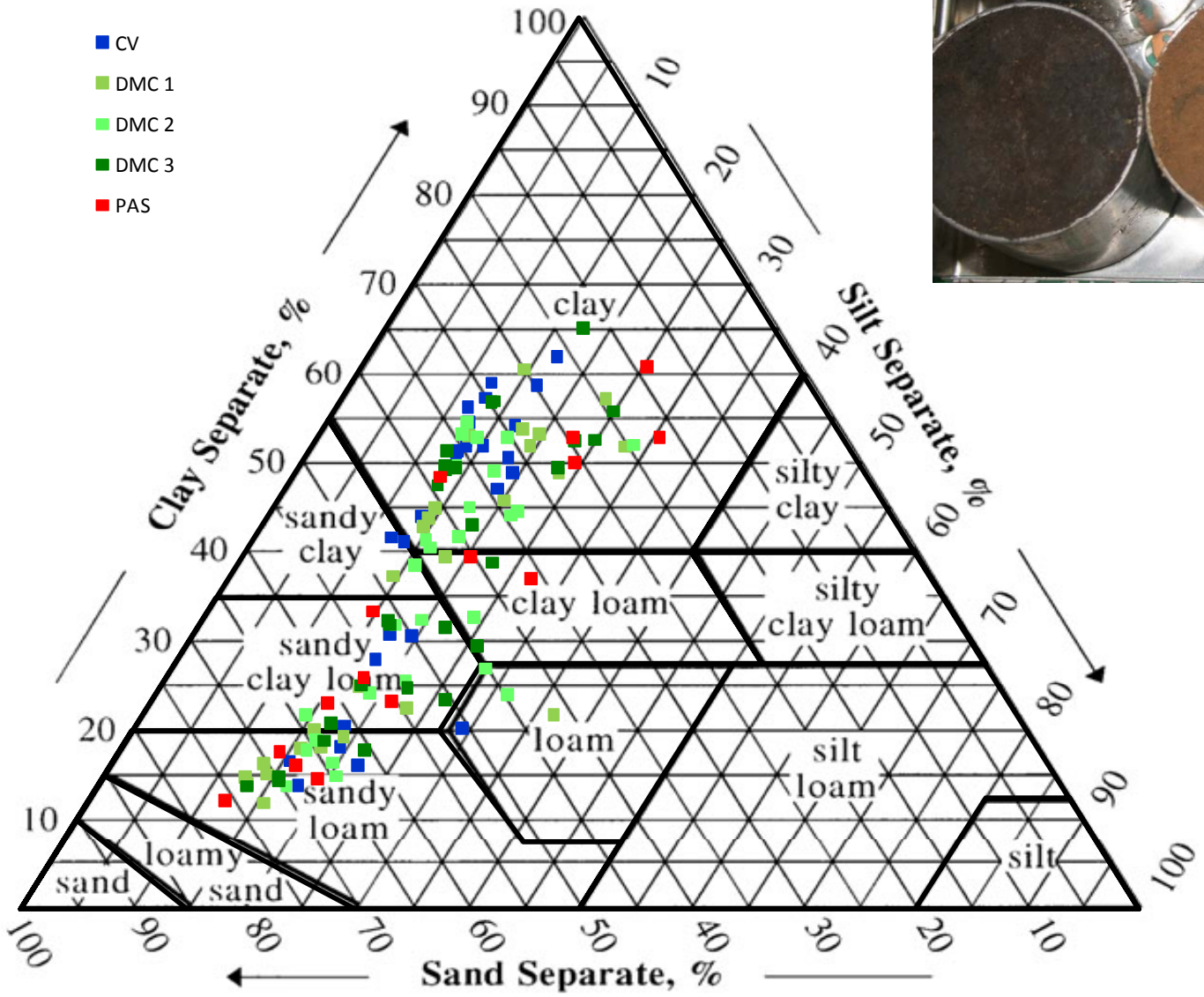


Land Use	Rep	Description
PAS	17	Savannah grassland dominated by *Themeda triandra* and *Cymbopogon nardus* species
CV	27	Land preparation based on ploughing using discs and burying of crop residues
DMC		No-tillage; direct seeding after mechanical and chemical control of cover crops
DMC 1	27	Year 1: "*fing*+*pig*", then 3y rotation rice+*sty* / corn+*fing*+*pig* / soy bean +*oat*+*buck*
DMC 2	27	Year 1: "*fing*+*sty*", then 3y rotation rice+*sty* / corn+*sty* / soy bean +*oat* +*buck*
DMC 3	27	Year 1 "*ruzi*+*pig*", then 3-year rotation rice+*sty* / corn+*ruzi* / soy bean +*oat* +*buck*

- **Treatments**



- **1 single experimental site but covering a high variability of:**
  - **soil textural classes**
  - **Soil colors**



- **Indicators**

  = variables allowing to translate a complex reality into more simple and readable forms (Mitchell et al, 1994)

Indication	Approach	Variables / tools
Soil texture and chemical properties	Soil analysis in laboratory	Texture, pH, Organic C, total N, avail P, CEC, Base (Ca, Mg, K, Na), BS
Soil structure quality - Soil macroporosity - Soil aggregate stability	 Undisturbed soil samples Wet sieving method (Yoder)	 Bulk density (Da) Water stable aggregates, aggregation indexes
Soil microbial abundance & diversity	Molecular tools (qPCR, B-RISA)	Total soil DNA, bacterial and fungal DNA, bacterial fingerprints

- **Indicators of soil structure quality**

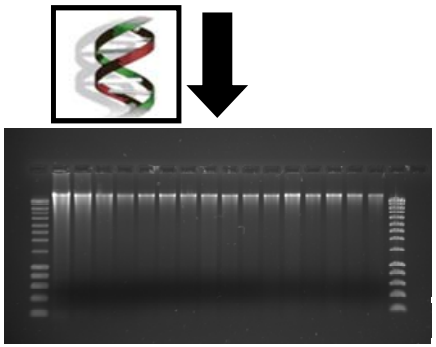
– Bulk density (Da) measured on undisturbed soil samples
(3 replicates /treatment)

- **Indicators of soil structure quality**

  - Water stable aggregates
  - Yoder method (1936) adapted by different authors (Haynes, Castro Filho *et al*, Madari *et al*)
  - 7 classes of aggregates obtained after wet sieving of soil samples through 6 sieves (mesh of 8, 4, 2, 1, 0.5 and 0.25 mm)
  - 3 replicates per treatment
  - 4 aggregation parameters:
    - Macro (0.25-19mm) and micro (<0.25mm) aggregate content
    - Mean Weight Diameter (MWD)
    - Mean Geometric Diameter (MGD)
    - Aggregate Stability Index (AS)

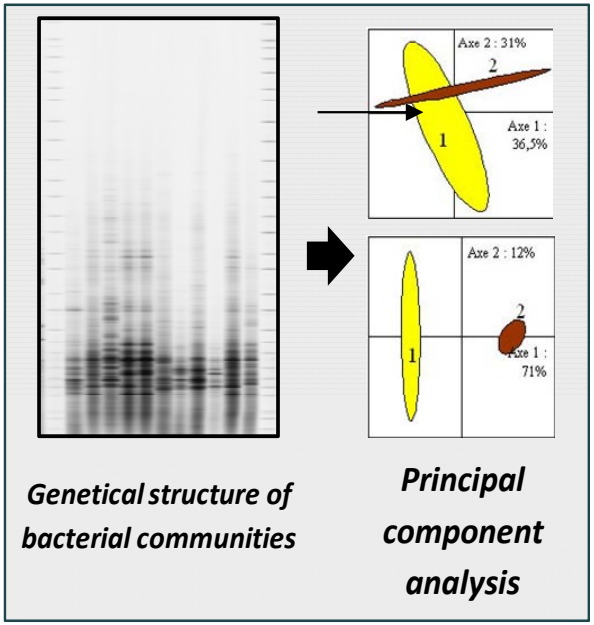
▪ Indicators of microbial abundance and diversity

Total microbial community



Soil DNA quantification (agarose)
= total soil microbial biomass

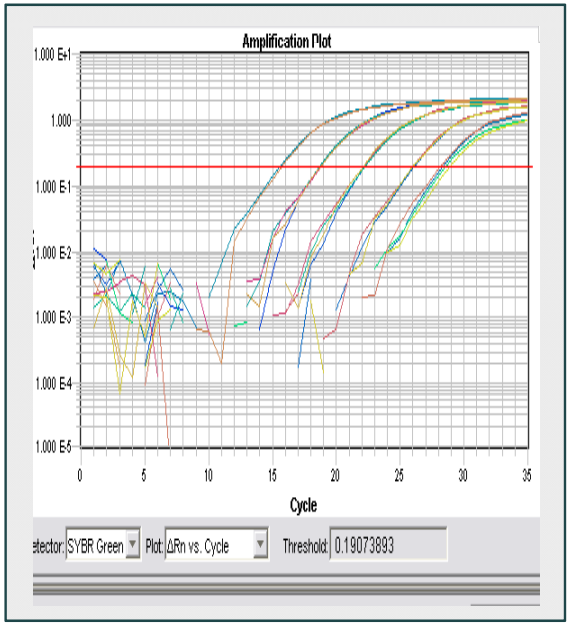
Molecular fingerprint
(B-ARISA)



Genetical structure of bacterial communities

Principal component analysis

Bacterial and fungal abundance
(qPCR 16 et 18S rDNA)



Adapted from Pascault, 2010 and Ranjard, 2009

- **Indicators**

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Soil structure quality - Soil macroporosity	Undisturbed soil samples	Bulk density (Da)
- Soil aggregate stability	Wet sieving method (Yoder)	Water stable aggregates, aggregation indexes (MWD, MGD, AS)
Soil microbial abundance and diversity	Molecular tools (qPCR, B-RISA)	Total soil DNA, bacterial and fungal DNA, bacterial fingerprints

Near Infrared Reflectance Spectroscopy (NIRS) predictive ability?

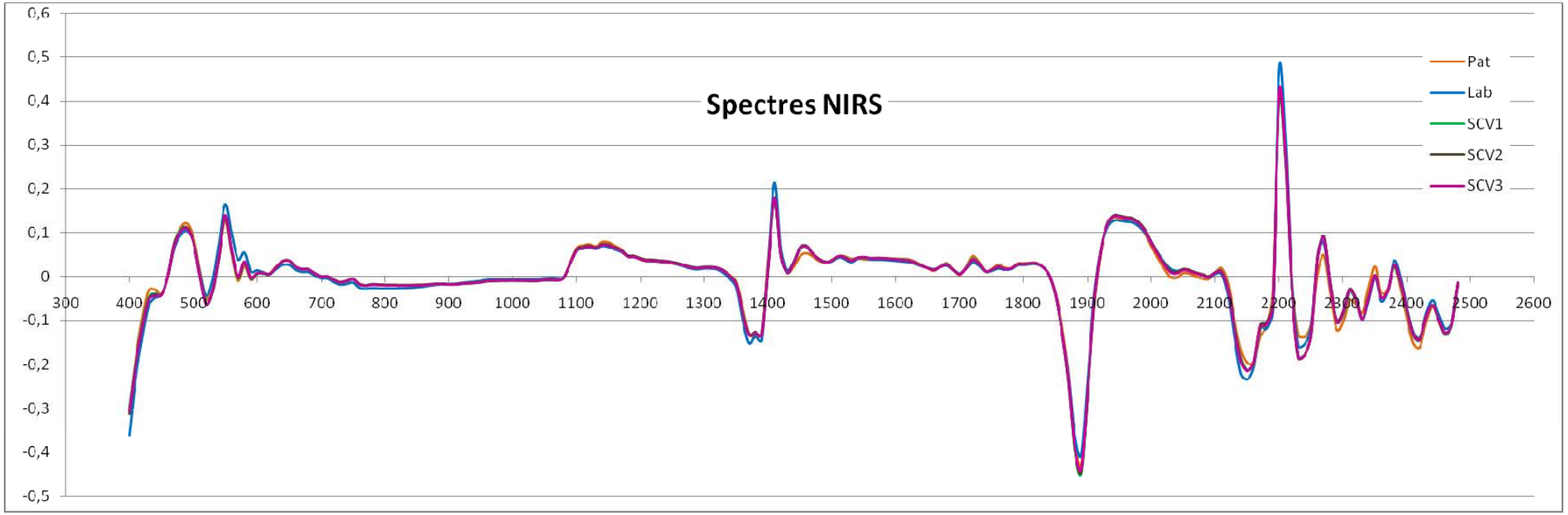
- **Near infrared reflectance spectroscopy**

– Soil sampling in June 2009
– Bulk of 5 soil samples for each treatment
– *In situ* air-dried and passed through 2mm mesh sieve
– NIRS analysis in France (CNRS-CEFE)
– Crushing of soil samples using a Cyclotec crusher (1mm mesh sieve)
– Soil placement in reading cells (quartz) and then measurement of reflected light in a spectrophotometer (NIRSystems 6500)



- **Near infrared reflectance spectroscopy**

– Spectral field from 400-2500 Nm, interval of measurement every 2 Nm, producing a spectrum made up of 1050 values of absorptance
– Predictions using winISI II software (v 1.50)



NIRS ability to predict soil texture

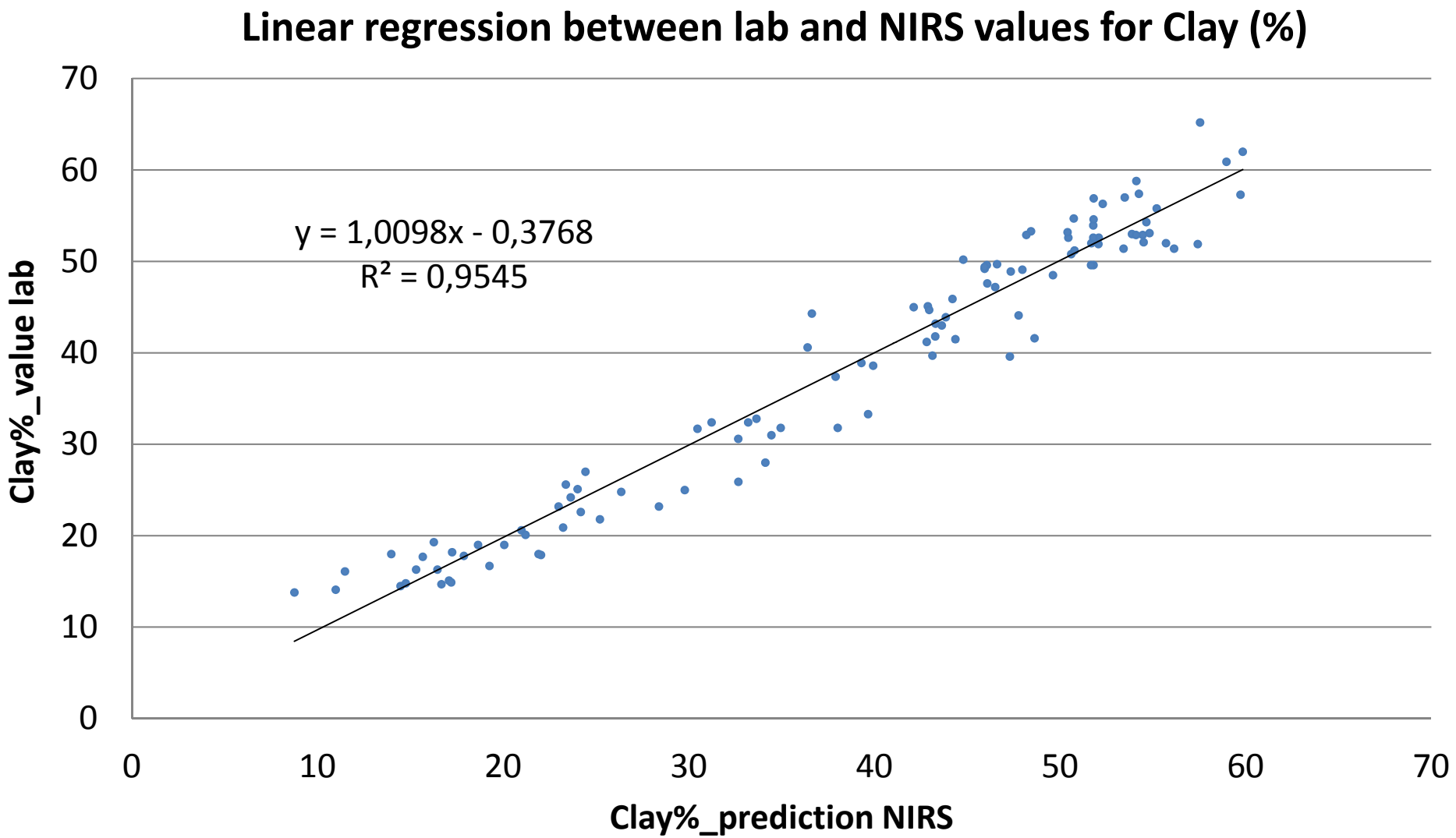
Constituent	Nb	Min	Max	Mean	SD	SEC	R^2	SECV	1-VR	RPD	Math treatment
Clay (%)	108	13,80	65,20	38,57	14,93	3,27	0,95	3,72	0,94	4,02	2, 10, 10, 1
Silt (%)	106	11,80	34,40	17,71	4,07	1,84	0,80	2,21	0,71	1,84	2, 10, 10, 1
Sand (%)	106	13,50	72,80	43,70	15,77	2,58	0,97	4,00	0,94	3,95	2, 10, 10, 1

SD: Standart deviation; SEC: Standart Error of Calibration

SECV: Standart Error of Cross Validation; 1-VR: % of variance explained by model

RPD: ratio SD/SECV; Math treatment: Derivate, Gap, Smooth 1, Smooth 2

- Highly satisfactory for clay and sand
- Useful to predict texture-related indicators (water holding capacity)


Linear regression between lab and NIRS values for Clay (%)
y = 1,0098x - 0,3768
R² = 0,9545
Clay%_value lab
Clay%_prediction NIRS
0
10
20
30
40
50
60
70

NIRS ability to predict chemical analytes

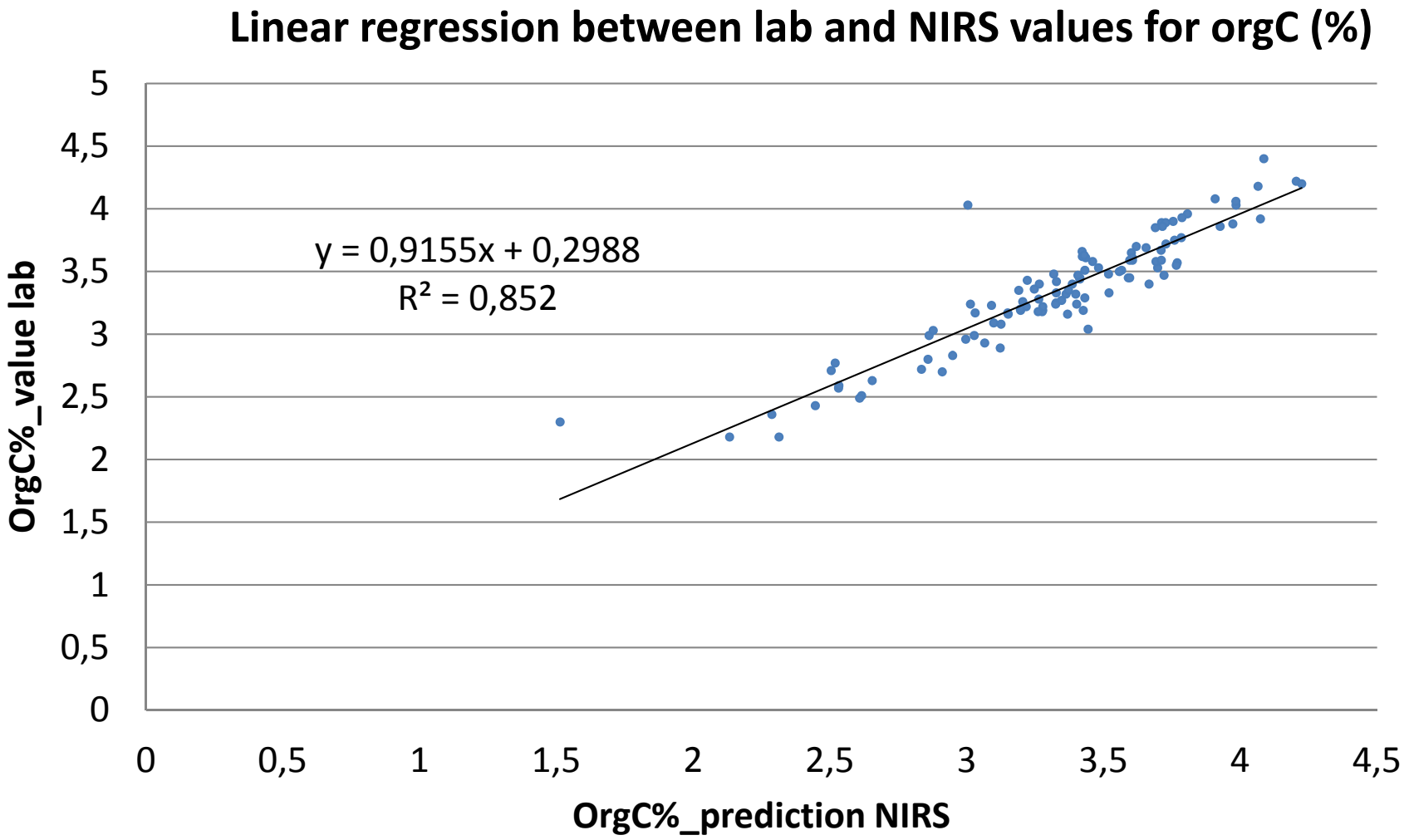
Constituent	Nb	Min	Max	Mean	SD	SEC	R^2	SECV	1-VR	RPD	Math treatment
Org C (%)	106	2,18	4,40	3,36	0,45	0,14	0,90	0,20	0,80	2,21	2, 10, 10, 1
Total N (‰)	106	1,71	3,42	2,36	0,35	0,14	0,84	0,17	0,76	2,02	2, 10, 10, 1
pH (1:5)	108	4,40	6,13	5,42	0,29	0,21	0,48	0,26	0,22	1,12	2, 10, 10, 1
Ca (me/100g)	108	0,11	5,44	2,50	1,17	0,53	0,80	0,71	0,63	1,64	2, 10, 10, 1
Mg (me/100g)	108	0,04	2,18	0,90	0,43	0,21	0,77	0,27	0,61	1,60	2, 10, 10, 1
K (me/100g)	106	0,05	0,51	0,18	0,08	0,05	0,58	0,07	0,37	1,25	2, 10, 10, 1
Σ base (me/100g)	108	0,35	8,10	3,63	1,66	0,69	0,83	0,98	0,66	1,70	2, 10, 10, 1
CEC (me/100g)	108	1,05	8,28	4,02	1,53	0,76	0,75	0,96	0,61	1,60	2, 10, 10, 1
Polsen (mg/kg)	108	2,00	18,56	8,96	3,70	2,30	0,61	3,03	0,33	1,22	2, 10, 10, 1

SD: Standart deviation; SEC: Standart Error of Calibration

SECV: Standart Error of Cross Validation; 1-VR: % of variance explained by model

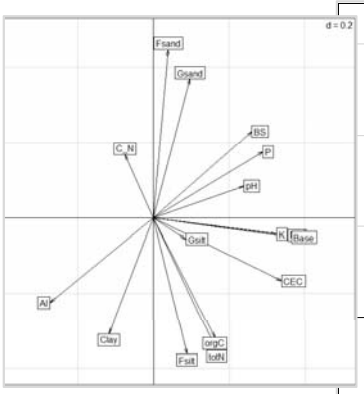
RPD: ratio SD/SECV; Math treatment: Derivate, Gap, Smooth 1, Smooth 2

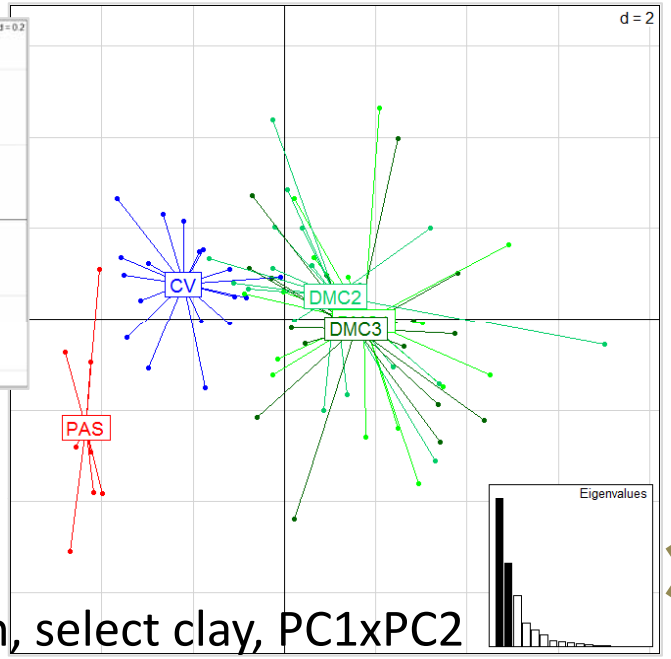
- Satisfactory for organic C and total N
- Moderately satisfactory for CEC, Ca, Mg and Sum of base
- Poor prediction for Polsen, K, Na and pH


Linear regression between lab and NIRS values for orgC (%)
y = 0,9155x + 0,2988
R² = 0,852
OrgC%_value lab
OrgC%_prediction NIRS
0
0,5
1
1,5
2
2,5
3
3,5
4
4,5
5

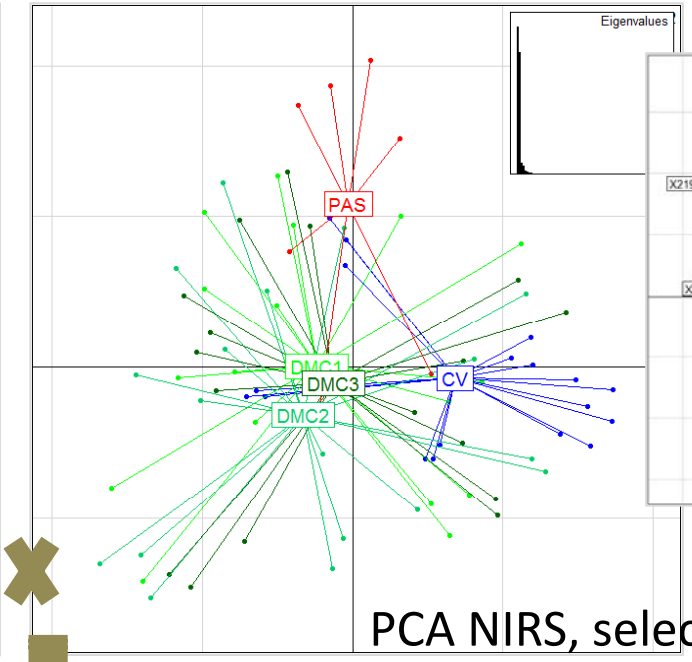
NIRS ability to predict overall chemical changes

- Trends of changes given by coinertia analysis

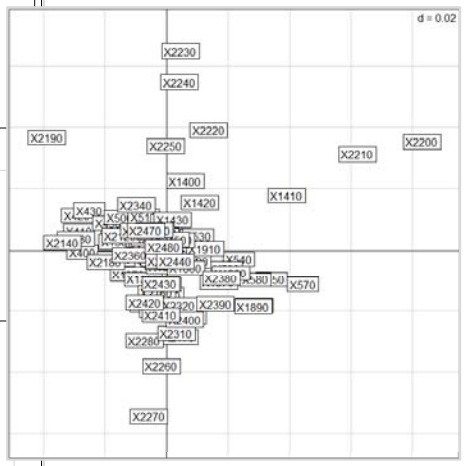


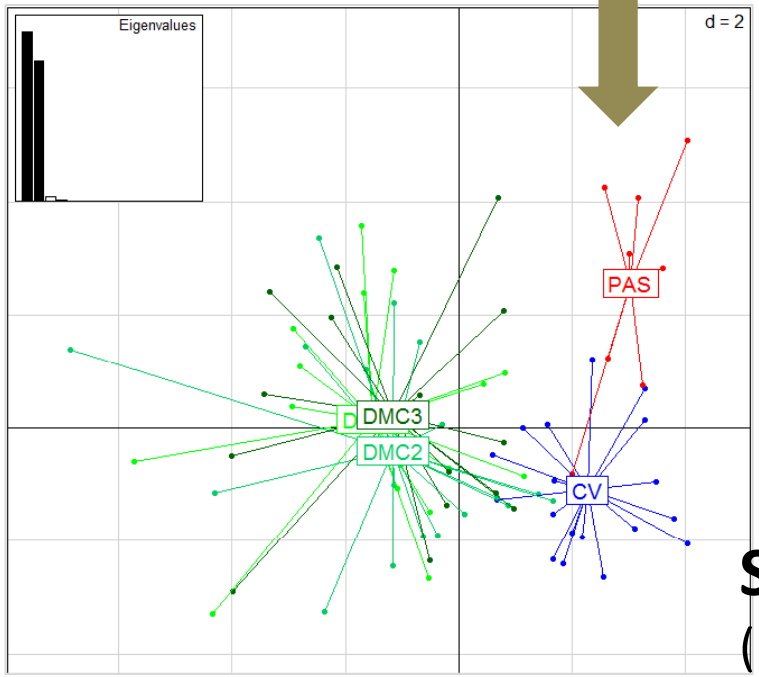


PCA text&chem, select clay, PC1xPC2



PCA NIRS, select clay, PC1xPC2



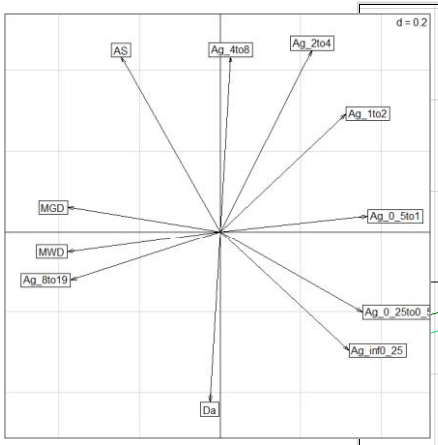


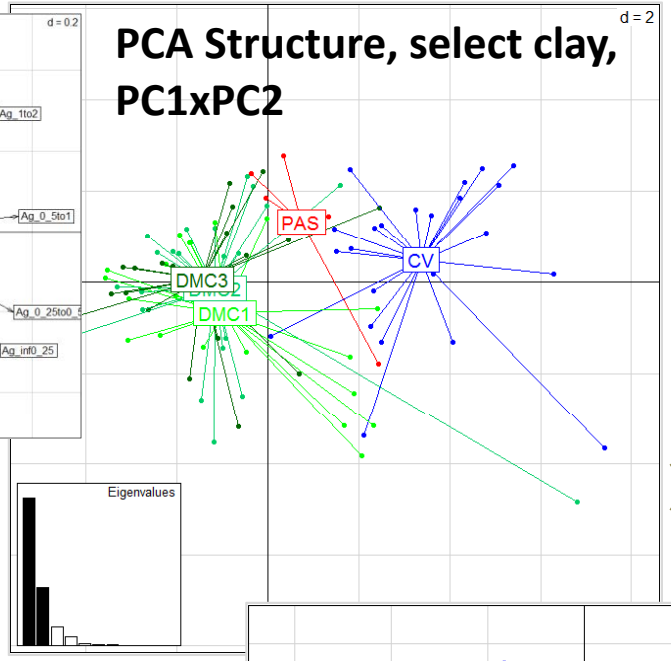
Significant coinertia analysis

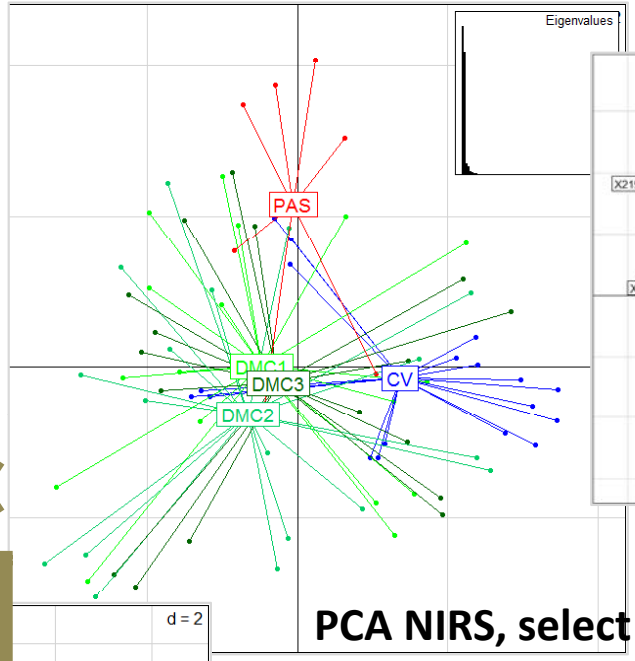
(Montecarlo test p-value: 0.000999001)

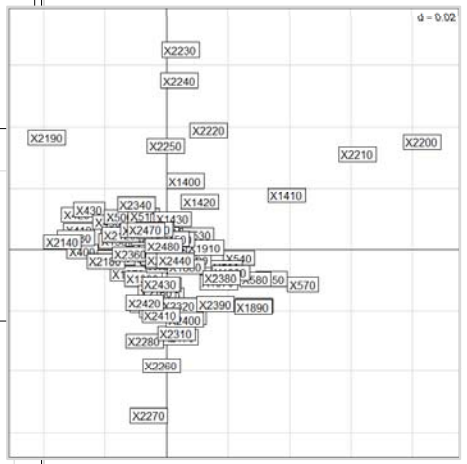
NIRS ability to predict structural elements

- Moderate (Da, 1-VR=0,62) to poor (WSA, 1-VR <0,45) predictions
- But trends of changes given by coinertia analysis

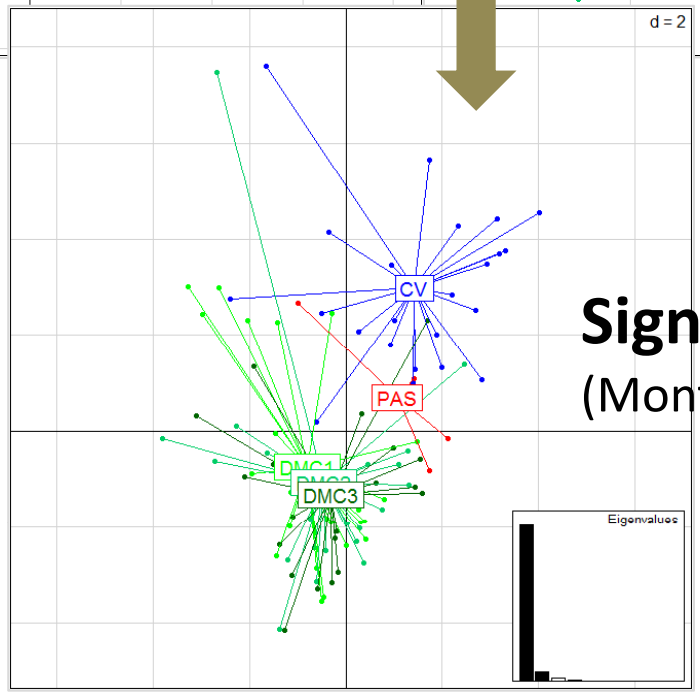








PCA NIRS, select clay, PC1xPC2

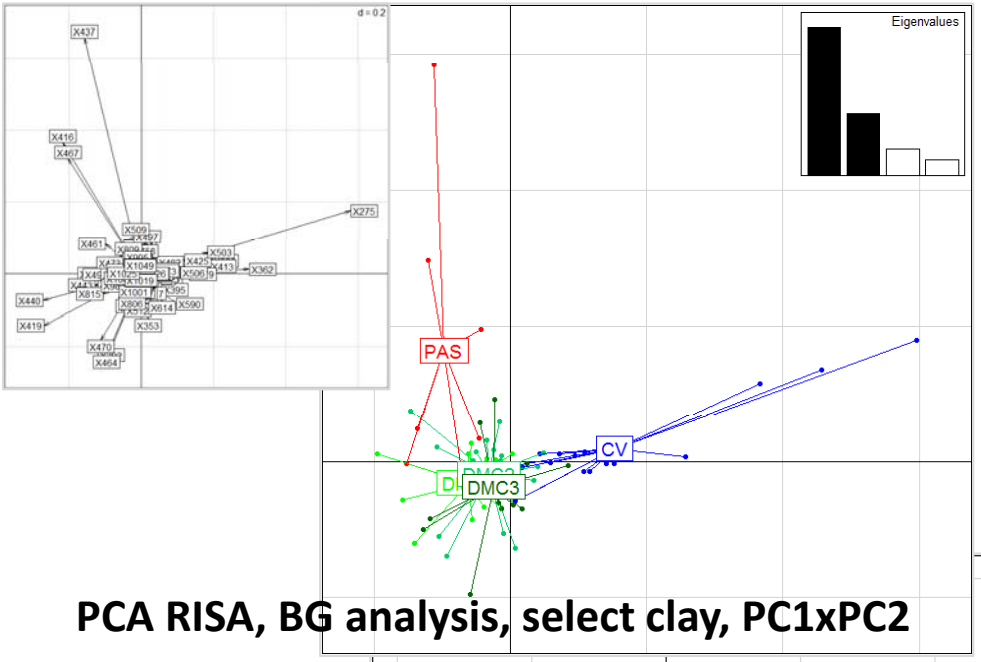


Significant coinertia analysis

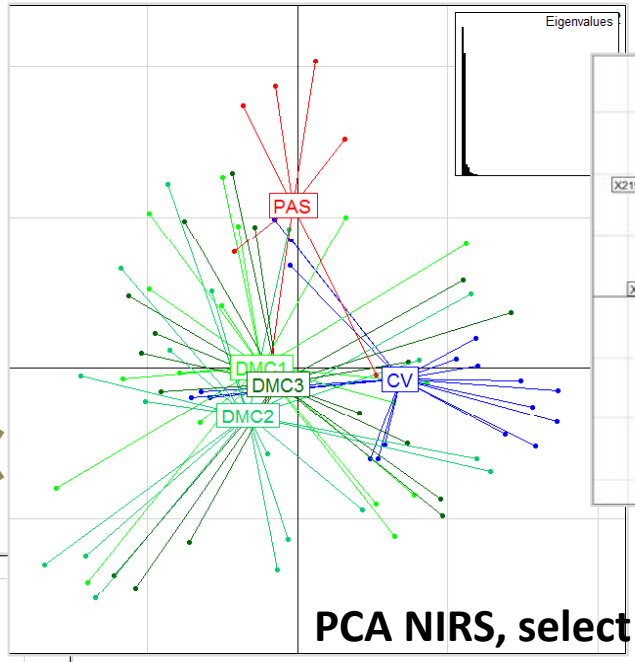
(Montecarlo test p-value: 0.000999001)

NIRS ability to predict microbial abundance and diversity

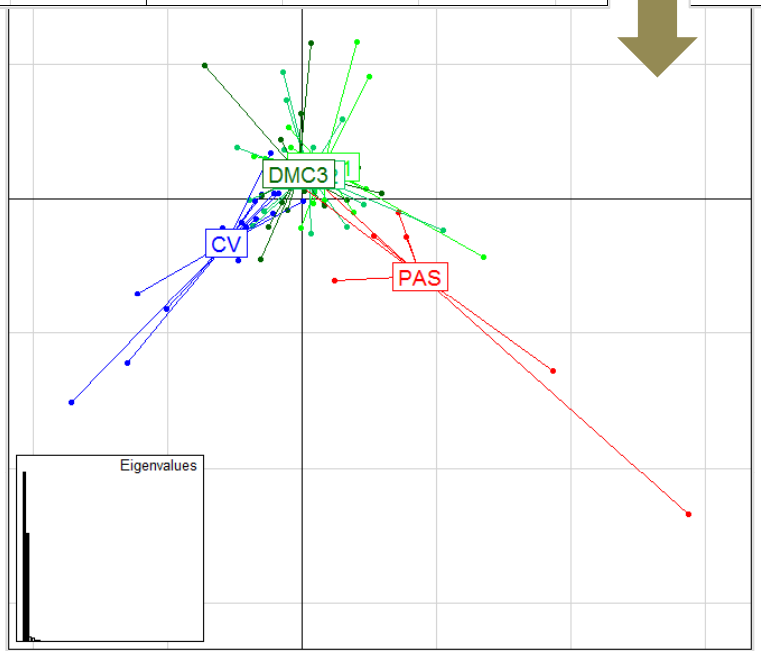
- Poor predictions for abundance (1-VR <0,35)
- But trends of microbial diversity changes given by coinertia analysis



PCA RISA, BG analysis, select clay, PC1xPC2



PCA NIRS, select clay, PC1xPC2



Significant coinertia analysis

(Montecarlo test p-value: 0.000999001)

Conclusions

- NIRS predictive potential difficult to assess on single case study since:

- 1 sampling site x 1 sampling period
  (1 soil matrice vs diversity of soil matrices and analytes forms)
- Unique samples processing
  (air-dried vs stove, cyclotec vs mortar,...)
- Unique samples analysis methods for chemical elements and NIRS (laboratory vs in situ)

- As described by other authors (review by Malley *et al*, 2004) the study confirmed the possibility to successfully determine by NIRS soil texture (clay, sand) and 2 main soil chemical components (organic C and total N)
- Qualitative information (trends) provided by NIRS regarding soil chemical properties, structure and microbial diversity changes were satisfactory since all coinertia analysis were significant (Monte carlo test p-value <0.001)
- Potential to be used (at least) for soil pre-screening and be integrated into sampling and analysis strategy
- Need of more spectral libraries to link NIRS spectrum with structural and microbiota data

Thank you for your attention !